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ABSTRACT

The central task of a 1980 workshop on the role of the National Aeronautics and Space Administration (NASA) in aeronautics was to examine the relationship of NASA's research capabilities to the state of U.S. aviation and to make recommendations about NASA's future role in aeronautics. The specific task of the Panel on Transport Aircraft was to identify NASA's role in commercial transport aircraft to delineate the segments of the spectrum of research and development activities that clearly must be within the purview of NASA in order for U.S. transport manufacturing and operating industries to succeed and to continue to make important contributions to the nation's well-being. Following an introduction, information is presented under these categories: (1) Status and Dimensions of the Air Transport Community; (2) Transport Aircraft Research and Technology Needs; (3) The Evolution of NASA's Role in Air Transport; (4) NASA's Role in Air Transport - 1980 and Beyond; (5) Conclusions; and (6) Recommendations. Definitions of roles and disciplines are included in an appendix. (Author/DS)

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NASA'S ROLE IN AERONAUTICS: A Workshop

Volume III Transport Aircraft

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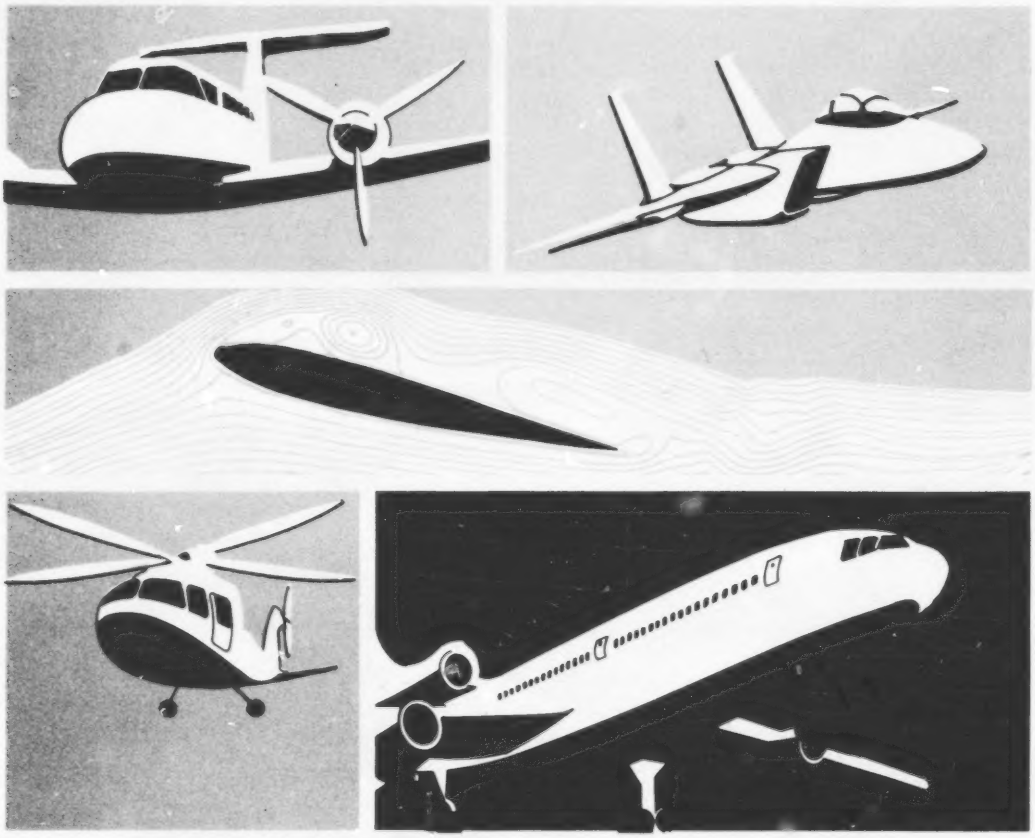

Report to the Workshop by the Panel on Transport Aircraft
Aeronautics and Space Engineering Board
Assembly of Engineering
National Research Council

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NOTICE: The project that is the subject of this report was approved by the Governing Board of the National Research Council, whose members are drawn from the Councils of the National Academy of Sciences, the National Academy of Engineering, and the Institute of Medicine. The members of the committee responsible for the report were chosen for their special competences and with regard for appropriate balance.

This report has been reviewed by a group other than the authors according to procedures approved by a Report Review Committee consisting of members of the National Academy of Sciences, the National Academy of Engineering, and the Institute of Medicine.

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WORKSHOP ON
THE ROLE OF NASA IN AERONAUTICS

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PREFACE

Aeronautics is changing in many significant respects. The implications of this are so far-reaching as to call into question the future position of the United States in world aviation.

The magnitude of this question, with its possible consequences for the nation's economy and security, led the National Aeronautics and Space Administration (NASA) to seek an independent evaluation from the Aeronautics and Space Engineering Board (ASEB) of the National Research Council's Assembly of Engineering. Specifically, the ASEB was asked to assess the nature and implications of the current state of U.S. aviation in a world setting and their significance for NASA's role in the nation's aeronautical future.

The ASEB responded by convening a workshop July 27 through August 2, 1980, at the National Academy of Sciences' Woods Hole Study Center. The workshop was structured into four panels covering military aviation, transport aircraft, general aviation, and rotorcraft. In addition, an overview panel was formed to consider NASA's role in research as well as its relationships with other elements of the aeronautics community.

The central task of the workshop was to examine the relationship of NASA's aeronautical research capabilities to the state of U.S. aviation and to make recommendations about NASA's future roles in aeronautics.

NASA and its predecessor, the National Advisory Committee for Aeronautics (NACA), traditionally have maintained a cooperative relationship with the aeronautical industry, with other government agencies concerned with aircraft operations and regulations, and with the academic community engaged in aerospace research. This triumvirate was taken into account in planning the workshop and selecting the participants. Thus, representatives from each part of the aeronautical community were invited, and information on NASA's relationship with each was the subject of special presentations prior to the working sessions. Representation from industry was predominant because industry's relationship with NASA is considered to be a key element in examining the present and future roles of NASA.

The members of the workshop panels represented, in total expertise and experience, all of the important sectors of aeronautics: military aircraft and missiles; commercial air transports; general aviation;

rotorcraft; university and private research; airline operations; and government regulatory agencies. In addition, the participants also included representatives of other industries--notably, automotive, electronics, and steel. Including the speakers and other nonpanel members, close to 80 individuals participated.

The participants were asked to address the issue of NASA's role in the context of a wider discussion concerning: the status and dimensions of U.S. aeronautics; the key aeronautical problems and opportunities that are likely to be amenable to research and technology development; the historical evolution and accomplishments of NASA in aeronautical research and technology development; and possible alternatives to NASA. Each of these subjects is discussed thoroughly in separate panel reports.

The report of the workshop consists of seven volumes:

I -- Summary

II -- Report of the Panel on Military Aviation

III -- Report of the Panel on Transport Aircraft

IV -- Report of the Panel on General Aviation

V -- Report of the Panel on Rotorcraft

VI -- Report of the Overview Panel on Aeronautical Research

VII -- Background Papers--The Outlook for Aeronautics and Relevant Areas

In order to help focus the discussion, NASA officials developed and provided a concise set of definitions of eight possible roles for NASA: National Facilities and Expertise; Research; Generic Technology Evolution; Vehicle Class Technology Evolution; Technology Demonstration; Technology Validation; Prototype Development; and, Operations Feasibility. Because some of these roles differ, depending on the aeronautical discipline involved, the roles are assessed within six principal aeronautical disciplines: aerodynamics, structures and materials, propulsion, electronics and avionics, vehicle operations, and human engineering. Definitions of these roles and disciplines are contained in Appendix A. The matching of the roles and disciplines is treated in Volumes II-VI and summarized in Section II of Volume I.

The workshop participants were extensively briefed by officials from NASA, the Department of Defense (DOD), and the Federal Aviation Administration (FAA), by leaders from the aviation manufacturing and operating industries, and by a member of Congress. The briefings are to be found in Volume VII.

Each panel separately considered the national benefits produced within the dimensions of its sector and the relative state of the sector's world position; each considered the evolution of NASA's role,

as well as a rationale for NASA's aeronautical support of its sector; and, finally, each panel produced sector-oriented conclusions and recommendations for NASA's roles for the future. Although there are obvious overlaps, the similarities and differences in each of the panels' findings are preserved in the separate reports of the sector-oriented panels, Volumes II-V.

This document, Volume III, presents the findings and recommendations of the Panel on Transport Aircraft.

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INTRODUCTION

Aeronautics is high technology. It requires a precise optimization of many engineering disciplines and developments, ranging from airfoils and thermodynamics to human factors and brakes. Mastery in aeronautics is one significant measure of the overall technological level of a nation. Recognizing the importance of aeronautics to their well-being, other nations are investing heavily in basic research, research faciilities, development, and manufacturing of aircraft and aircraft components in order to compete effectively with the United States for a greater share of the world aircraft market.

Commercial aircraft programs are long-term endeavors, and a declining trend in a nation's foreign sales of its aircraft is difficult to reverse. Moreover, new investment is more difficult for U.S. aircraft manufacturers than for government-financed foreign aircraft makers. Indeed, each new generation of aircraft requires greater investment outlays because they must contain advances in technology that are attractive to the airlines.

Current technological developments possess the potential for substantial improvements in fuel efficiency and operational economy. Examples of such new technology include large composite primary structures, active controls, improved power plants, engine-airframe integration, and, possibly, boundary-layer control.

A review of successful programs in the aircraft industry demonstrates that the driving force is provided by the synergy produced by technical cooperation and the energy produced by vigorous competition. The panel postulates, therefore, that fundamental research and technology development performed by government with the results shared among active industrial competitors benefits the nation. A vigorous, productive U.S. air transport industry provides jobs, contributes to the tax base, forms an essential part of the material transportation system, is integral to national defense, and makes a positive contribution to the nation's trade balance.

The specific task addressed in this volume is the identification of NASA's role in commercial transport aircraft--i.e., to delineate the segments of the spectrum of research and development activities that clearly must be within the purview of NASA in order for U.S. transport aircraft manufacturing and operating industries to succeed and to continue to make important contributions to the nation's well-being.

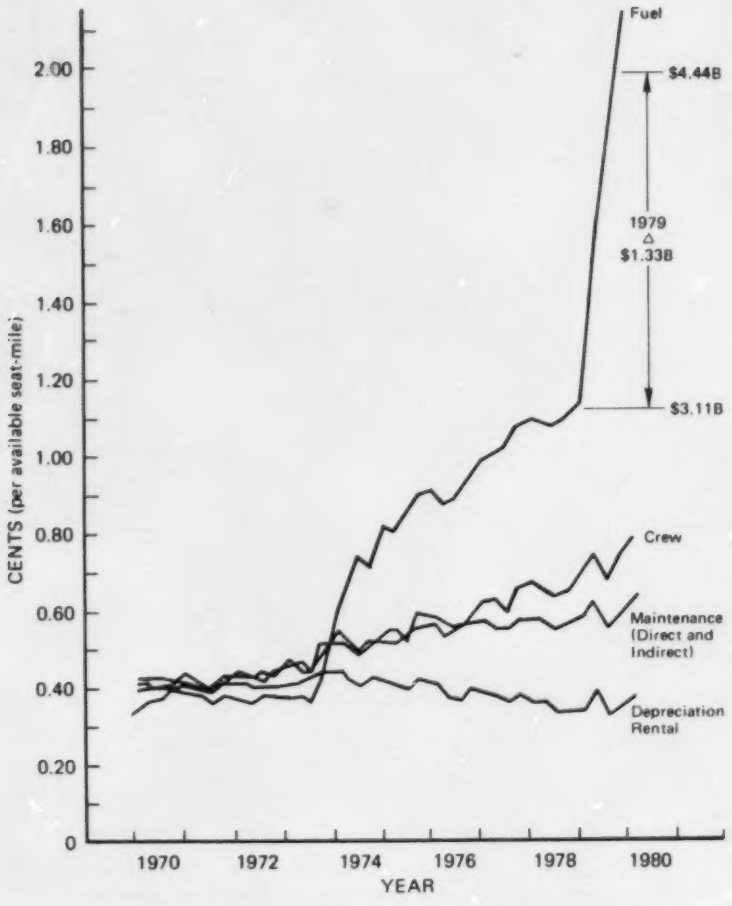
STATUS AND DIMENSIONS OF THE AIR TRANSPORT COMMUNITY

The 1980s will be a decade of unprecedented challenge for the U.S. commercial transport aircraft industry. For decades, it was characteristic of each new-generation of aircraft that its economics and capabilities were improved, largely by increases in speed and capacity, which were possible through advances in both airframe and engine technology. Technology provided the foundation for each new generation of aircraft. Major elements of this technology were developed through military funding of significant demonstration and development aircraft and engine programs in the 1950s. Today, military research funding is much more constrained. As a result, it is being devoted primarily to areas that are not adaptable to commercial air transports. Therefore, the development preceding new air transport technology must be supported in some other way.

During the 1950s, the Department of Defense and the National Advisory Committee for Aeronautics (NACA) developed the axial flow jet engine and the swept wing. These technologies were used for a new generation of aircraft that replaced the entire existing fleet of propeller-driven commercial transports--resulting in the 707, DC-8, 880, 990, 727, DC-9, and 737. The greatly improved speed, capacity, and efficiency of these aircraft may be found in about 5,000 passenger aircraft in the world today, most built in the United States.

Another significant development occurred in the 1960s. The introduction of high-bypass-ratio turbofans gave engines more than double the takeoff thrust and improved aircraft fuel consumption by more than 20 percent, as well as reduced engine noise appreciably. Consequently, it became possible to greatly increase productivity by increasing capacity. The 747 was the harbinger of a second generation of jet aircraft.

In the 1980s, fuel efficiency will be the most important new factor in commercial transport aircraft. The single major item of an airline's direct operating cost is now the cost of fuel. U.S. domestic airlines consume approximately 10 billion gallons of fuel per year. Figure 1 shows that the fuel price increases during 1979 alone raised the cost of airline operation by $1.33 billion. Each 1 percent



Source: Boeing Commercial Airplane Company study, 1980. Data derived from CAB form 41, schedule 45 (U.S. Trunk Airlines).

FIGURE 1 Elements of Direct Operating Costs

efficiency improvement represents a saving of about $100 million (at $1.00/gallon). Worldwide, this saving would be more than $200 million per year.

During the 1980s, the U.S. aircraft industry needs to be aggressive in applying advanced technology that is already available, as well as strive for technological improvements to conserve fuel if it is to maintain its world leadership in sales. Increased speed conflicts with the predominant need for fuel efficiency. Airfoils of the supercritical type that permit higher cruise speeds can be used to maintain today's cruise speeds at reduced fuel consumption. Thus, speed is not likely to contribute to airline productivity for the aircraft designer in the 1980s.

Also, greater capacity will not be a major design factor for the next generation of aircraft. Reasonable capacity increases can be achieved by extending the fuselage of existing airplanes, increasing

cargo capacity, and increasing seating density. These changes will not be of the magnitude that characterized previous generations of commercial transport airplanes.

The potential fuel-saving technologies of the late 1980s could spur the introduction of another new generation of aircraft. Reductions in fuel consumption as much as 30 percent below the fuel used by the current generation of wide-body airplanes are realistic (approximately 20 percent from the airframe and 10 percent or more from an advanced engine).

The constraints forecast for the air traffic control (ATC) system and major airports offer a significant challenge. These would need to be removed to improve the efficiency of the total air transportation system. Airport constraints arise from concerns about safeguarding the environment, reducing noise and emissions, as well as limits on runway capacity. ATC constraints are caused by saturation of the airways and airports during peak periods at many major airports and continuously at many hub airports. New technologies for both the vehicles and systems will be needed to eliminate or reduce such problems.

A new aircraft market, stimulated by deregulation, is opening for short-haul aircraft, with the commuter airlines growing at a rate of 15 percent per year. They serve cities and communities denied service by the trunk and regional airlines, plus major terminals.

The majority of aircraft in use by commuter airlines are of foreign manufacture. Except for two types, the few U.S. aircraft in use were developed from general aviation aircraft and are economically inadequate for the task. These aircraft seat, at a maximum, 19 passengers, but the industry is in need of an aircraft accommodating up to 36 passengers. Four new aircraft meeting such requirements are under development by foreign manufacturers, while only one type is being built in the United States. Moreover, the one being built in the U.S. is a joint venture with SAAB of Sweden, which is paying most of the development costs. The panel, therefore, considers that an aggressive development program, backed by research, is necessary or the U.S. commuter airlines will be primarily dependent on foreign-made aircraft.

Foreign aircraft producers are more advanced than U. S. manufacturers in important areas of aeronautical technology. For instance, Dassault, with French government funding, is proceeding toward the design, fabrication, test, and demonstration of a composite structure wing. This will include not only secondary structures, such as those researched by NASA to a point at which they are being adapted for U.S. designs, but primary structures as well. Significant payoffs lie in primary structure, but much more work needs to be done in this area in the United States. Another instance of technological advance is at Mitsubishi of Japan, which is nearly ready to offer a shadow-mask cathode-ray tube that will permit the use of advanced cockpit display concepts. These are two cases in which cooperation between foreign governments and their industries has resulted in relative superiority of technology over the U.S. Both are characterized by the high cost of the research required for developing the technology.

Fuel efficiency and system capacity will probably continue as the dominant challenges beyond 1990. Twice the 30 percent gain in fuel

efficiency anticipated by the late 1980s may be possible in the 1990s. In addition, opportunities can be projected for higher cruise speeds and the application of other technical innovations. Thus, it is expected that improvements will take place in productivity, fuel efficiency, economic operation, system capacity, and safety if advances in commercial air transport technology are developed.

Importance of a Vital U.S. Transport Aircraft Industry

When a key industry encounters difficulties, the whole economy feels the impact, as the current automobile situation shows quite clearly. The effect of the loss of automobile sales to foreign manufacturers is not confined to Detroit and the automobile manufacturers. It has had serious economic and social consequences for Toledo, Akron, Pittsburgh, and dozens of other cities that supply glass, tires, steel, and myriads of other components.

In this economic context, several facts are apparent with respect to the U.S. commercial aircraft manufacturing industry:

- The industry is a leading exporter, producing $35 billion in net export sales in the past 10 years.

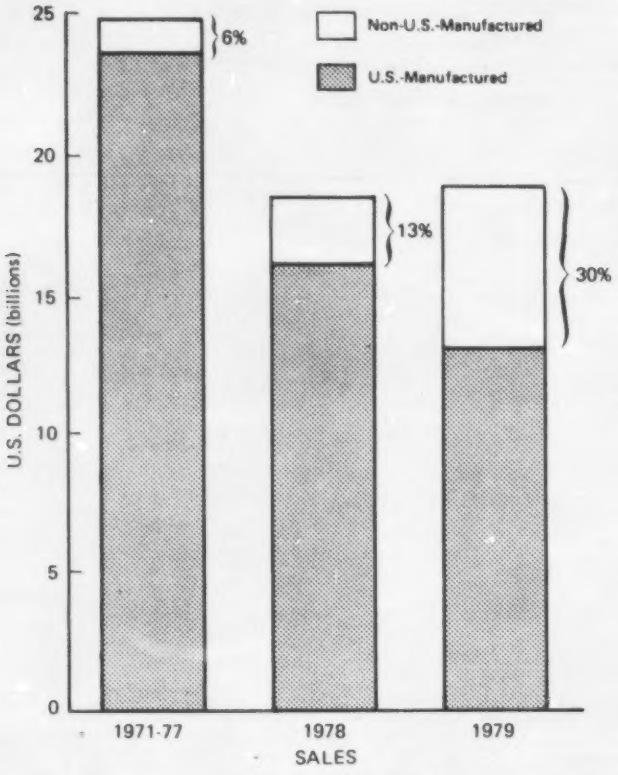
- In supplying the United States and the rest of the world, the industry provides hundreds of thousands of jobs. Currently, the industry accounts for close to 1,000,000 jobs in about 10,000 companies throughout all 50 states.

- The potential world market for future sales is immense--forecast to average more than $10 billion (in 1980 dollars) per year during the next decade.

- Although the U. S. industry is now dominant among all countries in the number of aircraft being delivered, orders placed during the last three years show sharp increases in orders for foreign aircraft--approximately 30 percent in 1979 (Figure 2). This portends a major loss in the U.S. share of future deliveries. If the trend continues, there could be over 100,000 fewer jobs in the United States in the near future. The resulting impact would be spread throughout the economy and parallel the adverse impacts caused by the decline of the auto industry. Moreover, the loss to the nation's balance of payments could be as high as $3 billion per year.

Beyond these economic and social reasons for maintaining U.S. superiority in aircraft sales, there are other important national benefits to be accrued from a vigorous commercial aircraft industry.

- The U.S. airline industry benefits from the availability of aircraft specifically designed for the U.S. market, meeting the high standards of economic performance, operational conditions, and environmental safeguards. Further, because Federal Aviation Administration (FAA) regulations presently serve as the airworthiness standard of the free world, U.S. air safety standards



Source: Boeing Commercial Airplane Study, 1980. Data derived from U.S. Dept. of Commerce Foreign Trade Reports, Series FT 410 and FT 246 (Annual Reports).

FIGURE 2 Free World Air Transport Sales

have been the model. This applies to well-established air transportation systems but are also expected to apply in the future to commuter and Vertical and/or Short Takeoff and Landing (V/STOL) aircraft as they develop.

- The high technology required by commercial aircraft benefits a broad range of other industries. Examples include filamentary composite materials for the auto industry, and large computer programs for stress analysis of airframes that are being used for such diverse tasks as naval architecture and washing machine design.

- There is direct transfer of commercial technological advances to the military, thereby improving the effectiveness of both military transport aircraft and combat aircraft.

- o A fleet of modern commercial aircraft is a national resource of immense value, should it be called upon in wartime. The more capable the air fleet and the greater its flexibility in use, the stronger is the nation's defense.

Preeminence in certain fields has intangible but nonetheless important benefits because of the impact of such superiority on the self-confidence of the nation and the respect it commands from the rest of the world. Commercial aircraft provide just such a demonstration of U.S. technology and power. Through commercial aircraft, the advanced state of U.S. technology has daily visibility throughout the world. For these reasons, the investment of national resources in transport aircraft development should be an important priority for the United States.

Finally, it is necessary to respond to the question of why tax money should be used to support aeronautical research. There are several obvious answers--one being the balance of trade. Between 60 and 70 percent of the commercial aircraft produced in the United States currently are for export, and sales of spare parts continue for years after the initial delivery. Thus, the research dollars spent assist an industry that builds about twice as much as is required for domestic consumption.

Second, in the air transport field, operating costs far exceed initial investment costs. Therefore, when new technology becomes available that promises to reduce operating costs, industry is motivated to make the investment required to use it. Clearly, the most effective way to provide support to the U.S. aircraft transport industry is through research and technology development.

The third reason is the depth to which the transport aircraft industry penetrates and stimulates the economic and social structure of the entire nation. Parts for aircraft are manufactured in every state.

The success of U.S. aeronautics constitutes the fourth reason. In NASA, the nation has witnessed a uniquely competent civil organization that has demonstrated it can apply tax dollars productively to research and development, stimulating an industry that has achieved unparalled international success.

Factors Affecting the Health of U.S. Transport Aircraft Industry

The primary purpose of this volume is to consider aeronautical research and technology needs for the air transport aircraft industry and, in particular, to consider the role NASA should play in satisfying these needs. It is important to recognize, however, certain nontechnical factors outside NASA's purview that have a significant effect on the current and future health of the industry. The following are some of the principal factors.

Proprietary Knowledge

New techniques and products resulting from basic research no longer remain proprietary for any prolonged period. NASA information is generally available and in use worldwide soon after its disclosure in the

United States, and the world aviation community is now in a technical and manufacturing position to take advantage of such knowledge. This has seriously reduced the leadership advantage of the U.S. manufacturers. To maintain leadership, the industry requires the backing of timely basic research, coupled with quick application to the final product.

Manfacturing Productivity

As with other U.S. manufacturing industries, improvement in productivity is essential to the future of the aircraft industry. Savings in cost and time are required in all stages of the process from research and development through manufacture, if the final product is to be competitive in the world market. Since the largest capital equipment expenditures and manufacturing costs are associated with the production phase, special attention is required for the development of advanced manufacturing technology.

Financial Considerations

The ability of the aircraft industry to generate capital for design, development, and manufacture of improved aircraft, engines, and other components must be maintained. The need for a healthy U.S. air transport industry that can generate the capital and afford the risk of committing to the launch of new aircraft programs is particularly important. This has been a critical ingredient in many past U.S. aircraft development programs.

TRANSPORT AIRCRAFT RESEARCH AND TECHNOLOGY NEEDS

The technology advances for future U.S. transport aircraft must be great enough to generate enough profits to allow a return of the capital investment within the aircraft's lifetime. It is unlikely that this can be accomplished by increasing productivity by increasing the speed and size of existing aircraft. For future transport aircraft and the systems in which they will operate, improved efficiency will be the primary means for achieving sufficient pay back. This is a formidable challenge.

Some of the improvements required are outlined in Table 1.

TABLE 1 Technology Advancements Required for Future Transport Aircraft

1. Reduced first costs:
   - Improved analytical methods
   - Improved manufacturing methods
   - Less dependence on source materials
2. Reduced cost of operation and improved fuel efficiency by:
   - Reduced airframe empty weight
     - large-scale adoption of composite structure
     - improved alloys
   - Use of active controls
   - Improved aerodynamics
   - Improved propulsive fuel consumption
     - better component efficiencies
     - advanced propellers
     - better performance retention
   - Optimized terminal and en-route operations
     - reduced delays
     - computerized aids to pilot
     - improved ATC routings
3. Evolve economically viable commuter airline aircraft:
   - Develop technologies
   - Improve fuel efficiency
4. Increase level of safety:
   - Human factors
   - Improved crashworthiness
   - Improved fire protection
   - Collision avoidance
   - Weather avoidance capabilities
   - Severe weather flying
5. Increased airways and airports capacity
6. Explore supersonic cruise capability
7. Increased fuel availability by making aircraft engines capable of operating, without degradation, with broad properties fuels
8. Explore reduced aircraft noise and emissions
9. Develop STOL capabilities

THE EVOLUTION OF NASA'S ROLE IN AIR TRANSPORT

By Congressional charter and in the national interest, a primary role for NASA is to assist the aircraft industry in maintaining U.S. leadership in transport technology. The indispensable ingredient of this leadership is a broad advanced technology base. This requires basic research, discovery, verification, validation, and, in some cases, demonstration and application. In this context, it is important to define the past contributions of NASA to the development of the technology base for air transport.

In any analysis of NASA's role in aeronautics, the first four of the 8 categories of work, defined in Appendix A, are considered essential. These are:

- o National Facilities and Expertise;
- o Research;
- o Generic Technology Evolution; and
- o Vehicle Class Technology Evolution.

NACA and NASA efforts in these areas have had a major influence in establishing and maintaining preeminent world leadership of the United States in aeronautics in general and commercial transport aircraft in particular.

One of the keys to technology development is the availability of special facilities such as the large NASA wind tunnels and simulators. These facilities must remain modern and efficient. Similarly, NASA's staff of competent, effective, and skilled personnel have contributed greatly to past developments. In the future, NASA's continuing efforts are considered by the panel to be an essential national resource.

Besides these fundamental roles, NASA, from time to time, has performed additional important functions. For example: many concepts require reduction to hardware (and, in this day of the digital computer, software), as well as extensive testing to demonstrate practicality. In such cases, NASA takes on further roles in Technology Demonstration and Technology Validation. Such programs can have both direct

and indirect effects on establishing and maintaining U.S. aeronautical leadership. The direct benefit is in the accomplishment itself, diffusing the results as a data base throughout the aeronautical community in a timely fashion. The indirect benefits can be equally dramatic in providing focus for significant studies, new technological subjects for researchers to pursue, and inspiration for the evolution of generic technology. Thus, synergism occurs both across the several possible NASA roles and among the members of the aeronautics community.

The NASA roles broadly discussed above are traditional and ongoing. They form a continuing part of the national aeronautical complex. A major question now facing U.S. policy makers as a national issue is: "What roles should NASA play in the national interest in the future?" The panel believes that clear and critical needs exist. As previously documented, the commercial transport aircraft market is not a free market, and U.S. transport aircraft are facing formidable competition.

Foreign governments have decided that, as a national priority, they will compete for a significant share of the commercial transport market. To illustrate, the following quote is from an editorial in the July 21, 1980, issue of Aviation Week:

> "Japan is overtaking the U.S. auto leadership...What is happening is of more than economic interest to aerospace. Aerospace will have its turn in the barrel before the decade is out...Overseas manufacturers are modernizing their aerospace manufacturing just as they have their automotive, steel, and electronic facilities. The challenges are coming...the silver lining for the aerospace industry is that it has been read a valuable warning, and there is time to react."

To help counter this growing threat, it is the panel's strong conviction that the national interest is best served by NASA support of an accelerated use of advanced technology by the U.S. transport aircraft industry as quickly as is reasonably possible. This role for NASA falls into the "Technology Validation" category. Elements of the continuing Aircraft Energy Efficiency (ACEE) program provide excellent examples of this role.

By way of elaboration, the panel has examined NASA's future role for the near-term (next 5 to 10 years) and the long-term (beyond the year 2000).

Near-Term Role

In the near-term, major research and technology development efforts are required to reduce the cost of transport aircraft operation

to cope with increased levels of transport operations, and to maintain or increase the safety of the total air transportation system.

Because fuel efficiency is a key to success in the 1980s, NASA's efforts should include the expansion of the fuel efficiency aspects of programs such as ACEE. Contributions to more efficient aircraft can be made through advanced supercritical airfoils, improved propulsion systems, active controls to reduce drag and structural weight without degradation of longitudinal stability, advanced aluminum alloys, composite materials, advanced airplane systems, and advanced avionics. A rational near-term target is that these technologies should provide for fuel efficiency improvements for new air transports of 30 to 35 percent over today's wide-body transport aircraft. They can be applied incrementally to transport aircraft in the 1982 to 1990 period.

Also, during this near-term period, NASA's considerable expertise and facilities should be devoted to the improvement of aviation safety and, in cooperation with the Federal Aviation Administration (FAA), to studies aimed at relieving both airway and airport congestion.

There is a great need for improved productivity in many American industrial sectors. In aeronautics, this translates into lower unit costs, which is related not only to the efficiency of manufacturing but to the manner and technology of design. Design technology must take account of manufacturing costs. The optimum objective is improved performance at lower unit cost. In some cases, such a combination is both possible and significant. Thus, the role of NASA must include an understanding of the application of manufacturing technology as it affects most phases of NASA's technical charter.

Far-Term Role

Far-reaching technologies require continued attention and effort. NASA should explore new frontiers that hold promise of increased productivity (speed/payload), improved efficiency (structural weight, engine specific fuel consumption, lift/drag ratio), plus greater safety. Effort also should be directed toward building an improved technical base for V/STOL aircraft.

Research in many of these far-reaching technologies carries implications for various vehicle types. Supersonic cruise technology --e.g., advanced metals, significantly improved lift to drag ratio, new engine cycles--can support both commercial supersonic transports and military aircraft. Laminar flow control has a large potential for improvements in military and commercial transports. Beyond the near-term improvements projected above, a further 25 to 30 percent increase in fuel efficiency appears achievable.

With respect to supersonic transport aircraft, NASA should study the elements of supersonic flight from the standpoints of aerodynamics, propulsion, controls, materials and structures. Since a supersonic transport aircraft as a vehicle design is still a distant prospect, money would be more effectively spent on the building blocks considered necessary to further such a design, rather than on integration of the design itself.

For the foreseeable future, the panel observes that aircraft jet fuels can be derived from alternate sources such as oil shale or coal, or cryogenic fuels such as hydrogen and methane. Should these fuels

prevent any special design problems for airframes and engines, research on the characteristics of these fuels definitely would be within the NASA charter and role.

Factors that Help to Define the Future Role of NASA

Because of the current state of the transport aircraft industry and its national importance, the panel concludes that circumstances will exist in which it is appropriate for NASA to conduct programs that move beyond the four basic categories previously cited. Such programs should be undertaken if circumstances indicate that the programs are in the national interest. These circumstances will, in general, be defined by combinations of the following factors:

- o Industrial knowledge of potential market;
- o Technological risk;
- o Profit potential;
- o Capital requirements;
- o Industry capability;
- o Gestation period;
- o Threat of foreign competition;
- o Potential impact on national welfare; and
- o Possible government regulation.

The Aircraft Energy Efficiency (ACEE) program is an excellent example. This program was initiated upon a request from Congress that NASA define, together with industry, a major program addressing both the accelerated application of advanced technology and the development of future technologies to conserve fuel. The primary objective of ACEE was to reduce overall U.S. transport fuel consumption and to make new U.S. aircraft more economically competitive. This program involved several of the factors listed above.

It is impossible to provide an accurate prescription of the exact situations for funding new NASA programs and the exact time periods for such programs. Certain general guidelines are possible to describe, however, and such descriptions are offered in each of the following role categories.

National Facilities and Expertise

NASA's existing facilities such as wind tunnels, simulators, and flight research facilities, are national resources of great value and in many cases are unique. As new requirements arise and older facilities become obsolete, expansions of and additions to these facilities

will be justified, as in the past, on determinations of the industry-wide usefulness, the capital outlay required, and the advantages of having new data enter the public domain. It is important to note that the replacement value of the facilities now exceeds $5 billion. The panel recommends that NASA maintain or obtain, as appropriate, the finest aeronautical research facilities in the world. Moreover, NASA's staff of highly competent, effective, and skilled personnel have contributed greatly to past developments, and similar high-quality personnel should be sought and retained in the future.

Research

The increasing capability of the transport aircraft industry to perform basic research in many fields does not supplant NASA's traditional role in this area. It supplements NASA's capacity. Despite the large industrial investment in research and development, industry has not and probably cannot invest a major portion of its resources in research requiring the long lead-time that usually is associated with basic or fundamental investigations. This is particularly true when the technological risk is great, the market is uncertain, and/or the investment return is questionable.

Examples of basic research conducted by NASA that have helped maintain U.S. aeronautical leadership include the development of (a) concepts of high-lift-devices for application to new military or commercial transport aircraft, (b) advice to both industry and government agencies about what is achievable in the way of noise reduction with turbofan aircraft, (c) advanced airfoils for application in all aspects of aviation, (d) advanced materials for both subsonic and supersonic flight regimes, (e) aeroelastic tailoring, (f) advanced engine technology, and (g) alternative propulsion systems.

Generic Technology Evolution

The purpose of Generic Technology Evolution is to move the state of the art forward in some technological aspect without concern for a particular aircraft type. Supersonic aerodynamics and reduced engine emissions are only two examples. Technological preeminence in these generic technologies is in the national interest. NASA's contributions in this area can make entirely new capabilities possible and can shorten the time required when industry does turn to developments requiring the use of such technologies. This makes possible an all-important time advantage in the world market for high technology aircraft.

Vehicle Class Technology Evolution

Vehicle Class Technology Evolution, while similar in character to Generic Technology Evolution, centers on those areas unique to a general class of flight vehicle such as large transport aircraft, rotorcraft, light general aviation aircraft, and high performance military vehicles. Concepts may evolve in response to a unique need in a particular class or may result directly from a potential applica-

tion of a concept evolved as generic technology.

The increased capabilities of the transport aircraft industry to perform research in many fields appears to alter NASA's traditional role in this area. As previously suggested, despite its resources, industry has not invested substantial portions of its research and development resources in projects requiring a long lead-time, particularly when a substantial wait is projected before achieving a return on a large investment. The deterrent is even greater if the return on an investment is slow, if the technological risks are great, if the market is not defined or is uncertain, and/or if the potential for investment return is questionable. Accordingly, research with high initial costs (such as projects requiring the construction of new facilities) is not likely to be undertaken. In those cases in which advantages are foreseen for the national welfare, NASA should undertake the development of vehicle class technology. Among other things, such investigations should identify problem areas likely to lead to advanced configurations, establish a data base for design purposes, and arrive at feasible new concepts for components critical to a new vehicle class for which there is little or no operational experience. In the absence of NASA's involvement in such tasks, it is likely that only foreign manufacturers, aided by their government, will be able to tolerate the long lead-time requirements. In such cases, they may achieve a lead that is so great that the U.S. industry will not be able to catch up or, if able to eventually compete, it will have lost sales valued in perhaps billions of dollars.

Technology Demonstration

Some areas of aeronautical research and development require a full-scale test demonstration or experimental flight test to obtain the technical data necessary to evaluate the concept or to reach a conclusion. For example, in the Energy Efficient Engine Program (E^3), it is essential first to assemble and test the individual components such as compressor, turbine, and casing, as a core engine, and then to retest the core with its fan and exhaust system to determine whether the performance of the whole is equal to the anticipated sum of the parts. This is because of the interactions that occur between one component and another. Turbine cooling depends on properties (pressure, temperature) of air delivered from the compressor; combustion performance is affected by the velocity profile exiting the compressor; the efficiency of the compressor and turbine is highly dependent on clearances between rotating airfoils and the stationary cases; this clearance, in turn, depends on the dynamic behavior of the rotor assembly in its bearings. Only by testing a full-scale assembly of components can it be determined if the desired level of performance has been obtained. Another example in which Technology Demonstration is required is work on large, composite, primary airframe structures. Only full-scale processing and testing will provide convincing answers about the technical feasibility of the concept.

The NASA role in Technology Demonstration becomes a necessary extension of its role in the evolution of technology when significant technical questions remain regarding either the feasibility of a con-

cept, because of uncertainties resulting from scale effect, or the interaction/interference between systems, vehicle components, or the operating environment. In any event, before such Technology Demonstration efforts are undertaken by NASA, the potential benefits of the technology must be judged to be high.

Technology Validation

These activities consist of programs that provide large-scale ground or flight validation as a necessary step to technology transfer. The purpose of such programs is to make possible, with reduced risk and without prohibitive development costs to industry, the practical utilization of high-benefit, high-risk conceptual, component, or subsystem technological advances. The results of the technology validation programs permit a risk and cost determination to be made, so that the U.S. industry may (assuming appropriate investment incentives are obtained) include the new concept in its next generation of aeronautical products.

An example of a technology validation program is the ongoing effort in secondary, medium, and primary composite structures. In this program, sufficient numbers of aircraft components have been fabricated in a manufacturing plant, certified by the FAA, and then placed in operational service to provide the manufacturer with detailed data on cost and risk.

NASA clearly has both the role and capability to undertake Technology Validation as a direct result of its technology evolution and demonstration programs. However, programs should be undertaken only when the application of a particular concept is specifically determined to be in the national interest.

In the discussion of NASA's role in Technology Validation one of the Transport Aircraft panel members from a nonaviation industry, while agreeing with the conclusion that NASA should have an important role in aeronautics in the areas of Research and Technology Evolution, questioned the arguments given in support of NASA carrying aeronautical programs beyond the level of Technology Demonstration into Technology Validation. He pointed out that the arguments for doing so were based largely on the size of the industry and the threat of foreign competition, each of which is equally valid for other U.S. manufacturing industries that are becoming noncompetitive in world markets.

The panel members stressed that public funds should not be used to assume a risk if the reward would be primarily to an individual company. Only in those circumstances in which industry could not recover its investment in a program deemed to be of primary benefit to society could the use of government funds be justified to reduce the risk of bringing a product of new technology into use. For example, he cited the federal government's clear responsibility to have adequate understanding of such environmental problems as noise and pollution so as to arrive at rational policies for dealing with them. Even so, he noted, it is not so clear that public funds should be used to develop specific hardware for solving the problems. Other alternatives, such as regulation, for example, must be considered, and the consequences of such alternatives weighed appropriately.

Further, he observed, although it was essential to maintain a technological lead to remain competitive in the world, the current problem involving foreign competition in aeronautics was based largely on political and business factors and not on technological considerations.

Prototype Development

Technology demonstration hardware described are never final products. Such programs are designed to answer questions of technical feasibility, not to meet competitive market pressures, user desires, or manufacturing limitations. Currently, NASA aeronautics programs do not extend to the point of involvement in prototypes of transport aircraft or engines. Only if the Congress recognizes that there is a national need for NASA involvement in prototype transport aircraft activity should such be considered appropriate.

Operations Feasibility

Another class of aeronautic development that requires testing and evaluating involves new concepts in the operating system environment. For transport aircraft, the need for such testing is obvious for programs such as automated air traffic control systems, laminar flows, all-weather landing systems, or other control systems involving human factors (crew or ground personnel). NASA has demonstrated its ability to effect the necessary coordination between regulatory agencies, operators, and manufacturers in conducting operations feasibility tests. NASA's continued involvement in this process will serve to provide the confidence needed to proceed with improvements in the domestic air transportation system.

CONCLUSIONS

Most research items considered by NASA involve combinations of the judgmental factors listed in Table 2. Each case usually reflects some application of each judgment factor, but only the most significant or key indicators are listed.

Table 3 illustrates the manner in which the judgmental factors can be weighed to determine the degree of NASA participation in each step; one or more examples are provided for each category.

In Group I, laminar flow was chosen to illustrate the point that some areas of research require progression through all of the steps to a demonstration of operational feasibility. In the case of laminar flow, operational feasibility is the question.

Technologies for reducing noise and engine emissions are generally lacking in economic incentive. Wing vortex alleviation, another concern, may have an adverse impact on noise and on critical aircraft safety characteristics in the approach mode. Industry will rarely invest scarce resources in generic and fundamental research in areas of societal concern without a potential competitive advantage. There are notable exceptions. Perhaps the best example is the high-by-pass engine, which yielded more fuel efficiency and less noise at the same time. NASA has made significant contributions to solving these problems in the past, and the panel concludes that this important role should be continued in areas of public concern.

Some areas of NASA research are of moderate technical risk; some of these technologies, however, are of vital national interest because of the large favorable impact they have on fuel conservation. NASA participation, at least through the first four or five levels of Table 2, is essential to accelerate the development and incorporation of the best prospective technologies. Other examples of national concern that may fall into this important category are crashworthiness, flight safety, and the evaluation of alternative fuels.

Figure 3 provides a matrix of roles and disciplinary areas. The matrix is annotated to indicate that NASA's role with respect to the first four categories is to provide support under all circumstances. These are the "irreducible minimum" needs of the transport industry. Decreasing levels of responsibility are seen in the remaining role categories as dictated by circumstances, either technological or societal.

TABLE 2 Grouped Categories

Judgemental Factors	I Very High Technical Risk	II High Risk	III Societal Concern	IV Moderate Risk	V Long Term Opportunity
Market Risk	Uncertain	High	High		High
Technology Risk	Very High	High		Moderate	High
Industry Capability				Good	
Capital Risk		High		Moderate	
Gestation Period		Long			Long
Profit Potential			Low	High	
Societal Concern			High		
Foreign Competition				High	
[Regulatory Potential]			High		

TABLE 3

Grouped Category \ Defined NASA Role	1 Facilities and Expertise	2 Research	3 Generic Technology Evolution	4 Vehicle Class Technology Evolution	5 Technology Demonstration	6 Technology Validation	7 Prototype Development	8 Operations Feasibility
I • Very High Technical Risk • Uncertain Market *Example:* Laminar Flow	√	√	√	√	√	√		√
II • Technical and Market Risk and Capital Requirements - High • Long Gestation Period *Example:* Composite Structure	√	√	√	√	√	√		
III • Societal Concern - High • Market Risk - High • Profit Potential - Low • Regulation Potential - High *Example:* Vortex Alleviation ATC Interface Noise and Air Pollution	√	√	√	√	√			
IV • Technical Risk and Capital Requirements - Moderate • Foreign Competition and Profit Potential - High *Example:* Fuel Conservation Advanced Turboprop	√	√	√	√	√			
V • Long-Term Technical Opportunities *Example:* Hypersonics	√	√	√	√	√			

NASA ROLE CODE
1. Major Role
*2. Moderate Role
*3. Minor Role
*– No Role

ROLES	AERODYNAMICS	STRUCTURES & MATERIALS	PROPULSION	ELECTRONICS & AVIONICS	VEHICLE OPERATIONS	HUMAN ENGINEERING
NATIONAL FACILITIES & EXPERTISE	1	1	1	1	2	1
RESEARCH	1	1	1	1	2	1
GENERIC TECHNOLOGY EVOLUTION	1	1	1	1	2	1
VEHICLE CLASS TECHNOLOGY EVOLUTION	1	1	1	1	2	1
TECHNOLOGY DEMONSTRATION	1[a,b]	1[a,b]	1[a,b]	1[a,b]	2[a,b]	1[a,b]
TECHNOLOGY VALIDATION	1[a]	1[a]	1[a]	1[a]	2[a]	1[a]
PROTOTYPE DEVELOPMENT	3[a,c]	3[a,c]	3[a,c]	3[a,c]	3[a,c]	3[a,c]
OPERATIONS FEASIBILITY	2[a,d]	2[a,d]	2[a,d]	2[a,d]	2[a,d]	2[a,d]

NOTES:
(a) When national interest dictates
(b) Where components must be combined to evaluate the whole or where experimental flight testing is required
(c) With Congressional approval
(d) High risk - only way to evaluate

*If a proposed project or program initially falls in a recommended moderate, minor, or no-role category, but, following review of its merits on an individual case basis, is deemed to be a desirable undertaking by virtue of its being in the national interest, or mandated by the Congress or as a result of review it is concluded there are other overriding circumstances, then NASA's role for that project or program would be elevated to a major one (i.e., Category 1).

FIGURE 3 Air Transport Role/Discipline Matrix

RECOMMENDATIONS

Because of the importance of air transportation to the nation's economy, and the contribution of the transport aircraft manufacturing industry to the balance of trade, the panel's primary recommendation is that the U.S. government fully support the NASA role as described here, enabling the agency to continue to enhance its performance of aeronautical research and technology development. The need for this research is particularly acute in light of the participation of foreign governments in aeronautical research. Such participation could erode the U.S. share of the world market. The need for research also is critical in view of the importance of technological improvements needed for the next generation of transport aircraft. Specifically, the panel recommends that NASA's aeronautical role include, without qualification:

- The maintenance of National Aeronautical Facilities and Expertise,
- Research programs to gain basic understanding of physical phenomena in all aeronautical disciplines, and
- Technology Evolution programs (both Generic and Vehicle Specific) to pursue research results that show promise of generating a technology base for application by U.S. industry;

and the following activities when in the national interest:

- Technology Demonstration
- Technology Demonstration and Validation
- Prototype Development, only when the above condition is met and the program is authorized by the Congress, and
- Operations Feasibility

APPENDIX A

DEFINITIONS OF ROLES AND DISCIPLINES

To facilitate the task undertaken by the participants in the ASEB workshop, a series of definitions of possible roles for NASA was developed. The roles represent steps in the hierarchy of the research and development process, beginning with a desire for knowledge and an understanding of basic phenomena, an idea, or technical concept, and ending with the design and construction of a vehicle, a vehicle component, or a new operational system.

Definitions of Possible Roles for NASA

Each of the following eight roles as defined by NASA was reviewed by the participants, and the panels considered the extent to which NASA should carry out these roles.

National Facilities and Expertise

This category comprises the development and maintenance of test facilities, including wind tunnels, simulators, and computers, as well as the maintenance of personnel with specialized skills, technical knowledge, and expertise in the field of aeronautics.

Research

Programs in this category are designed to gain basic knowledge and understanding of physical phenomena and processes in all discipline areas relevant to aeronautics. The work is fundamental in character and is performed within NASA, at universities, in industry, and by independent research organizations.

Generic Technology Evolution

This category involves the pursuit of the results of specific lines of basic research that show promise of generating technology broadly applicable to a number of classes of vehicles. The work is evolutionary in nature and leads to the continued advancement of technology.

Such advances generally precede focused technology development in support of specific vehicle class needs. The work is conducted primarily within NASA, with appropriate university and industry support.

Vehicle Class Technology Evolution

NASA programs in this category concentrate on specific vehicle classes and on the preparation of the unique technology data base required to improve the design and development of certain classes of aircraft. Activities include generating and evaluating new concepts and configuration approaches for the vehicle classes. Examples include V/STOL and supersonic cruise vehicles. In both cases, the technologies unique to those classes of aircraft are examined with regard to design feasibility, benefits, costs, etc. Then tailored data bases are developed.

Technology Demonstration

This category includes programs that are conducted to demonstrate the technical feasibility of a technology advance or concept. Activities may include flight testing and component or systems demonstrations. Specific examples in the current NASA program are: Tilt-Rotor Research Aircraft, Energy Efficient Engine, Quiet Short-Haul Research Aircraft, and Terminal Configured Vehicle. Future modifications and tests on an aircraft to demonstrate the feasibility of Laminar Flow Control and flight tests of an Advanced Turboprop would be included in Technology Demonstration.

Technology Validation

This comprises programs that include large-scale ground or flight validation as a necessary step to assure technology transfer. The purpose is to make possible, with minimal risk and without additional technology development, the practical utilization of high-benefit, high-risk conceptual, component, or subsystem technology advances. Specific examples in the present NASA program are: Composite Primary Aircraft Structure (CPAS), Materials for Advanced Turbine Engine (MATE), and Engine Component Improvement (ECI).

Prototype Development

This category consists of design, development, construction, and testing of an aircraft, engine, or system that is sufficiently representative of a planned final product to serve as a production prototype. An example of such a program for the civil sector would be the supersonic transport (SST) program conducted by the FAA during the 1960s. Current NASA programs do not include any prototype developments, and none is currently planned.

Operations Feasibility

This refers to operations conducted as research directed toward evaluating the feasibility or practicality of aircraft system operations to meet special needs or requirements or to demonstrate that a total, integrated operational system (e.g., new aircraft or simulated new aircraft, advanced integrated flight systems, approach and landing techniques, wake vortex alleviation, etc.) provides a service or benefit. The economic, environmental, and/or social aspects are considered.

Definitions of Disciplines

Aerodynamics

Aerodynamics is the science dealing with the motion of air and other gases and with the effects of such motion on objects moving through such media.

Structures and Materials

This is the portion of aeronautical research and technology development dealing with the design of structures (the part of the aircraft, missiles and/or their components whose function is to carry loads in the broadest sense) and the materials used in aircraft and missile construction.

Propulsion

This disciplinary heading includes the part of aeronautical research and technology development relating to the various methods and systems for generating and delivering power for propelling and/or lifting aircraft and missiles.

Electronics and Avionics

Electronics refers to that aircraft and missile electrical equipment that is required for the basic operation of the vehicles--e.g., flight and engine controls. Avionics means the electrical equipment used for mission functions, such as air-to-ground communications and navigation. In military aircraft and missiles, the latter category includes offensive and defensive equipment and weapons control systems.

Vehicle Operations

This area deals directly with operational problems encountered by aircraft and missiles, such as icing, detection and dissemination of weather information, and air traffic control systems.

Human Engineering

This discipline addresses the study of human capabilities and problems that occur at the interfaces between the crew and the aircraft. It includes work on and use of simulators, crew workload studies, and studies of the optimization of cockpit instrumentation and controls.